Review on Signalling in Indian Railways and Way for the Future

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The need for having better signaling system which ensures safety, has gained more demand after the inclusion of electronic systems like track circuits, axle counters etc., into railways. Signaling problem is more severe in India because of its huge population and most of them are relying on railways. To serve the needs of passengers, Indian railways has introduced many electronic signalling systems, but survey shows that there is still scope for improvement of the safety standards which improves reliability of railway networks. This paper presents various signalling methods which includes ETCS,GSM-R,CBTC and their standardizations that were followed in India and new ideas for further improvement of signaling is presented.

Keywords: Track circuits, Axle counters, ETCS, CBTC, GSM-R, ATP, AWS.

2023. In Saroj Hiranwal & Garima Mathur (eds.), *Artificial Intelligence and Communication Technologies*, 91–100. Computing & Intelligent Systems, SCRS, India. https://doi.org/10.52458/978-81-955020-5-9-9

1. Introduction

In India, railways play a major role in transportation of man and material from one place to other. Majority of the people are reliant on railways because of its cost to comfort ratio. Recent survey shows that Indian railway (IR) network [1] is 4^{th} largest network in the world by size, with 67,368km of route length and 121,407 km of track length which runs more than 20,000 passenger trains daily from 8,500 stations of India serving all classes of people.

First commercial train journey in India is kept on track between Bombay and thane on April 16^{th} , 1853 for a journey of 21 miles in length and 45 minutes of time. But there is no fixed signalling method [2] at that stage, so trains were driven based on hand-held signals that are in visible range of the loco pilot, which led to many real-time problems like, collision of trains. Due to lack of failsafe breaking mechanism, many hazardous accidents had happened which caused damage to man and material, hence Indian railways had decided to go for fixed signalling. Signalling system of railways has grown gradually from semaphore to multiple aspect colored display signalling (MACLS) [3]-[5].

Due to exponential increase of passengers from the years gone by, efficient utilization of the track has become a major issue that we need to address here. In order to meet these constraints we had to increase the frequency of trains on the existing tracks. This can be done by dividing the entire track into certain fixed length of blocks (Fixed block signalling) to decrease headway between the trains. Block signalling [6]-[8] is all about leaving a block (section of track which is of fixed length that is controlled by the rear station) between two successive trains travelling on the same track. The block systems are primarily to ensure that there is always.enough space between trains to allow a following train to stop, before it hits the one ahead of it. This is done by dividing the track into blocks by using some components like, Track circuits and axle counters. Currently IR is using a gap of 2 blocks (length of 2km each) between successive trains as a preventive measure. Track circuits are integral part of the block systems, they are basically electric circuits that monitor the train moments based on the electromagnetic induction (EMI) between the rails. Track circuits and axle counters are made mandatory by IR long ago even in AC traction (not totally electrified) and Dc traction (totally electrified) areas as shown in figures 1 and 2. Track circuit has the ability to detect the broken rails also.

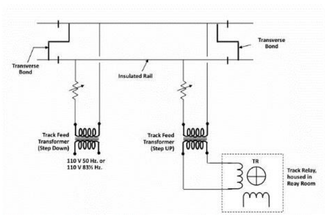

Figure. 1. A.C Track Circuit

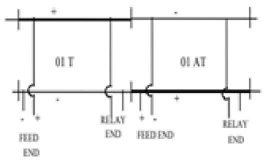

Figure. 2. D.C Track Circuit

In addition to the track circuits IR uses axle counters which are simply wheel counters of the train as shown in figure 3. IR uses it as a safety measure in addition to the track circuits for second level checking. It consists of a simple circuit that has incremental counter on its head which counts number of axles passes on it. They are digital devices which gives the information to the wayside equipment that is forwarded to the control room. This operation can be done by incrementing and decrementing the axle count and front and back ends respectively. The axle counter goes to null when the train had departed from the block completely otherwise it indicates that the track is occupied.

An operating range of 15 km and low operating voltage of 2.4V is an added advantage over track circuits. Several drawbacks like power failure, manual overwrite and improper resetting etc. makes it inefficient to work solely so IR uses both Track Circuits and axle counters for better reliability.

Rather than relying up on simple track circuit with low operating distance an Audio Frequency Track Circuits (AFTC's) [9]-[10] is introduced which sends modulated electrical signals at particular frequencies ranges up to few KHz. AFTC's also increases its operating range up to 500m or above using different kinds of joints. The pioneers in using AFTC's was Southern Railways and Central Railways (CR) among which CR has implemented High Frequency Track Circuits (HFTC) which ranges up to few MHZ of frequencies. There are several types AFTC's as shown in figure 4

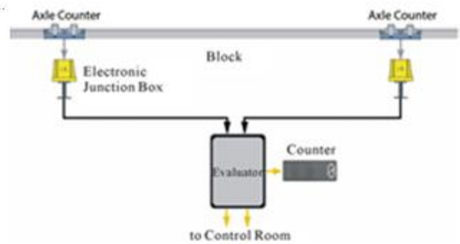

Figure. 3. Axle Counter

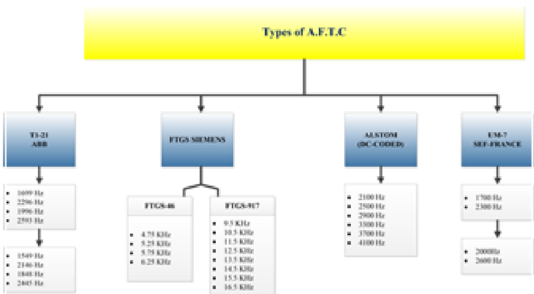

Figure. 4. Types of AFC's

In addition to signalling, routing is also an important aspect in railways. The routing in IR is done by a mechanism called as interlocking [11]. As we all know trains can't route themselves to destination. A routing map has to be provided to the loco pilot in order to check whether the train is going in prescribed direction or not. The actual routing was done by tracks because a loco can't steer the train but follows the signals which were given by the signal controllers. If there occurs any critical situation the track has to be rerouted following the instructions from the control room that is situated in every station which runs under the supervision of the concerned station master.

The following diagrams represent the working of a signalling block when the track is occupied by a train or when it is left empty as shown in figure 5.

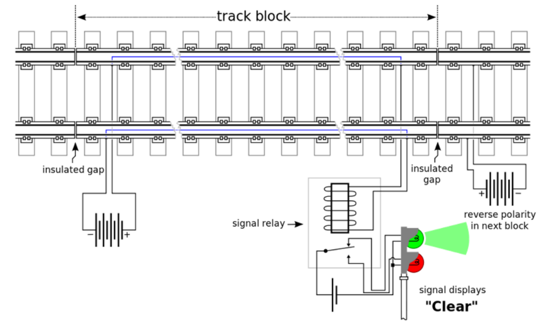

Figure. 5. Block is Empty

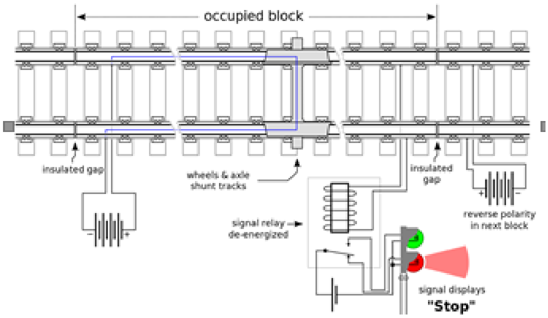

Figure. 6. Block is Occupied by a Train

As mentioned above the entire track is divided into blocks that is of different types in Absolute Blocking System (ABS) mechanism [12] where the train is divided into series of sections such that, when one train is occupying a section of the track no other train is allowed to enter in that section as shown in figure 6.

Intermediate block system (IBS) mechanism refers to a system where, sometimes a long stretch between two stations may be formed into two or more block sections (intermediate block) in order to increase the track utilization. This block is an additional block section which does not essentially corresponds to any section.

Moving block system (MBS) refers to a mechanism where the track is divided into some real time block sections (MBS) where the information is captured by real time computers. It identifies the safe location by obtaining information about speed of the trains running on that track at any time instant by using GPS, thereby increasing the track utilization. Various track utilization mechanisms and their brief explanation on various issues in IR are discussed above. Section II describes about various preventive methods which were taken by IR. Section III describes about various research standardizations, section IV describes about current scenario of IR and the way to go in future for it, and finally section V concludes the paper.

2. Research Efforts on Preventive Methods by IR

Even though IR implements many fool proof signalling, there are some flaws in the system to mitigate those problems. To make train journey safer than before, an Indian Railway Research board namely Institution of Railway Signal and Telecommunication Engineers (IRSTE) has introduced some safety systems like Auxiliary warning system (AWS) [13], Train protection and warning system (TPWS), Train Management System and Data logger systems etc.,

AWS is a special notification system which was introduced to get the upcoming aspect signal information in advance, to the motorman's display panel in EMU (Electronic multiple unit) as shown in figure 7. This is done by track side equipment which was started in western railway later it was implemented by central railway in 1990's. These pilferage problems are also resolved most recently and it was also made compatible with trains running more than 100 kmph.

The Train protection and warning system (TPWS) [14] is a critical collision avoidance system whichapplies breaks to a train in some critical situations like fast signal crossing by train, emergency brake failure at appropriate signal, crossing the danger signal leading to collision etc., Here two sensors namely train stop sensor (TSS) and over speed sensor(OSS) are used to avoid the collision of trains running at a speed up to 120kmph by placing them at either ends of the block section. A TPWS system is defined as a combination of two systems namely Automatic Train Protection (ATP) and Anti-Collision Device (ACD). ATP provides auto breaking system which prevents the train from crossing the danger signal, it acts as an aid to the loco pilot when the manual breaking fails, and it can control the train which is running up to 120 kmph as shown in figure 8. ACD is a computerized equipment used to derive the location, speed and direction of the train using Global Positioning System (GPS). These ACD's work on Angular Deviation Count principle which are fixed on several locations like locomotives, guard vans, stations and level crossing gates etc.,

Train Management System (TMS) is a system implemented by westren railway in 2013 and it is followed by central railway for integrated management and maintainance of sub-urban railways. At that time system of train control does not match highly intensive traffic requirement of suburban section and also controllers have no visual display of train movements so that station staff has to manually keep record of each train movement.

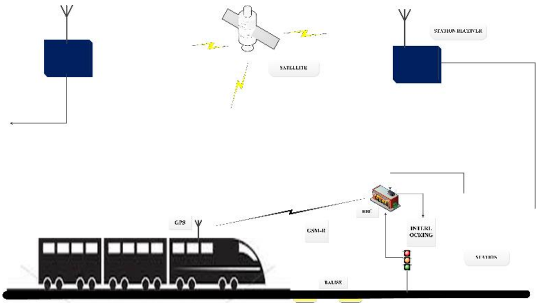

Figure. 7. AWS of IR

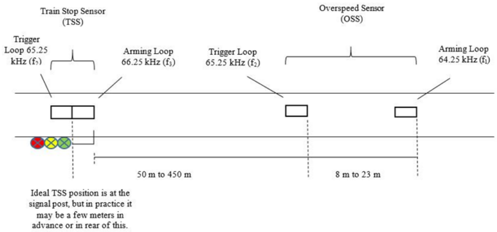

Figure. 8. ATP of IR

There is no real time information to passengers about expected arrival time of trains so the TMS [15] fecilitates all the above mentioned issues.

Data Logger System (DLS) [16] is a tracking system used to take preventive measures by monitoring and updating the railway traffic data continuously. A data logger is an information storage unit, which gathers all the information regarding the signalling of components and way side equipment at a frequency of 5-50 times per second as shown in figure 9. This information is forwarded to central computers mostly located at divisional headquarters. These central computers generate reports on several kinds of malfunctions such as power failure, signal jamming etc., by raising alarms at EMU.

3. Standardization of IR Signalling

Being one of the largest commercial network in the world, IR strictly follows many standards for the smooth functioning of railway traffic. Till now IR signalling is based on standards proposed by European Committee for Electro technical Standardization (CENELEC) [17]. Some of the standards are used for Reliability, Availability, Maintainability and Safety (RAMS) and Communications, Signalling, and Processing Systems (CSPS) as listed in table 1.

The EN50126 standard describes the terms of RAMS and their process based on system lifecycle for managing them. It is used mainly to reduce the conflicts between RAMS elements and to manage them efficiently, but it doesn't define RAMS targets, quantities, solutions for some specific railway applications.

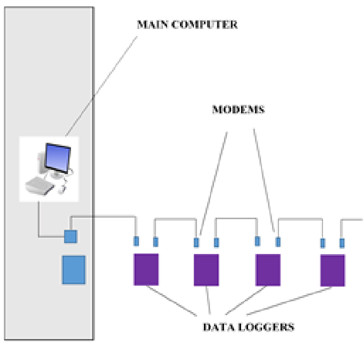

Figure. 9. Data Loggers system

Table 1: CENELEC Standard

CENELEC Standard	Application
EN50126	The specification and demonstration of RAMS
EN50128	CSPS- software for railway control and protection systems
EN50129	CSPS- safety related electronic system for signalling
EN50159-1	CSPS- safety related communication in transmission.

Table 2: system integrity level Standard

PHR per hour	SIL
$10^{-9} \leq$ PHR< 10^{-8}	4
$10^{-8} \leq$ PHR< 10^{-7}	3
$10^{-7} \leq$ PHR< 10^{-6}	2
$10^{-6} \leq$ PHR< 10^{-5}	1

The EN50128 standard is aimed to specify the technical essentials for the evolution of programmable electronic systems used in railway control and protection applications.

The EN50129 standard specifies the lifecycle activities which should be completed before the acceptance stage. These activities will be carried to the next stage of acceptance

The EN50159-1 standard gives the basic prerequisites which are essential for achieving communication between safety related equipment and the transmission system. In order to meet the safety and integrity requirements. From the above standard a measure of safety integrity level based on the passable hazard rate (PHR) is defined as shown in table 2. From table 2 it is evident that system integrity level is the most hazardous comparatively.

4. Current Scenario of IR and the Way to Go in Future

The need of having better signaling based on electronic systems, was identified during 1990s. It became more important after the introduction of high-speed trains on the existing tracks. In Europe, it was standardized as ETCS systems, with different levels of implementation. In Europe, as there are different train companies belonging to different countries, following uniform signaling was also considered after the formation of European Union, with cross-border movements of trains [18]. At level-1 of ETCS, it was intended to bring to the notice of driver, the signaling information in electronic format. At level-2, it is intervention-based system, where the driver also confirms the adherence of the command. At level-3, it is of total automation, which leads to the control of train from control center itself, with minimum intervention of driver.

The impact of European railways in India is very high, starting from the ERTMS followed by ETCS level 1, currently upgraded to level II and in future versions of it. Most of the IR systems currently running are using ETCS level-2 signalling system, which uses a Resource Block Centre (RBC) to collect the information from the wayside equipment continuously. These RBC's are linked to signal and interlocking systems by using optical fiber cables for transferring the gathered information. India has been following very closely with the European railway systems due to the nature of traffic that Europe had, is almost similar to India. Whereas outside Europe, GSmany countries like India and china, and under disposition in some gulf countries also.

Wireless communication with GSM was proposed as the supporting technology for ETCS level-2 namely GSM-R (GSM for railways), by adding some mission critical communication options to GSM. Now LTE-R is being explored, in the place of GSM-R [19], [20].

ETCS level-1 and 2 are using fixed block mechanism whereas ETCS level -3 follows Moving block mechanism of CBTC[21-22] which is currently implemented in Indian trains like Train 18 (Vande Bharath) set on tracks from February 2019 which was inaugurated by honorable prime minister of India and looking to implement it in future trains. At present, ETCS is at various stages in different countries of Europe, many of them between level-1 and level-2. IR, from the last few years, is contemplating to use advanced signaling systems. A few trails also have taken place with multiple technologies [23-24]. There are reports in the recent times again about the proposal of bringing such advanced signaling systems into use [25]. On board requirements of CBTC is defined in the IEEE standard 1474.1.

In CBTC, determination of position of train using GPS and communicating it over GSM-R on to the loco pilot cabin by using the RFID just like in ETCS for identifying the position with high precision. It is also independent of the track circuits and the wayside equipment, so that it can reduce the man-made errors as shown in figure 10.

Safety is the major criteria for any system especially for such an intense network as railways. It is the vital component which needs to be taken care of by the Train Borne equipment and the wayside Track equipment, which provides continuous protection for the train.

Optional backup systems are needed to safeguard any system failure. To install it in such a large network is a challenging task itself, which has to be fool proof, and it has also implemented some strategies like independent train detection which may be used as a backup mechanism.

We need the location information (GPS) and un-interrupted coverage (GSM-R) to work with CBTC as they are the key components of any autonomous train working with CBTC.

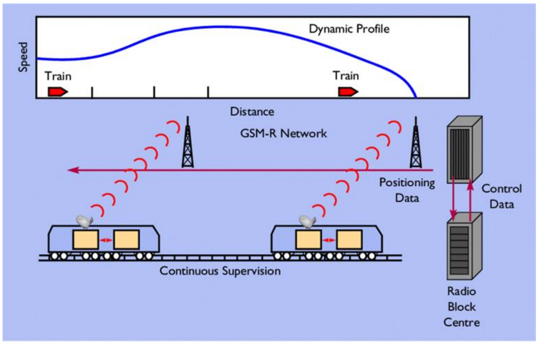

Figure. 10. Communication Based Train Control

In a CBTC based system train calculates its position by on board equipment, with reference to a stored line map. The train position is transmitted to a central control system via radio communication using GSM-R or RFID

Thus, the central computer has exact position information, thereby it calculates the train target speed, ATP which is already installed on the train regulates its speed. CBTC can work autonomously, without these systems like ATP and all, but they are already part of the existing system in IR, which can be kept as backup mechanism. The survey had shown that, there is a lots of scope for improvement in the area of signalling in IR. One of the ways for the future is superseding the existing trackside components with wireless sensor nodes, with the implementation of Time Slotted Channel Hoping (TSCH) following IEEE 802.15.4 for 6LoWPAN [26] networks we can achieve deterministic data transfer with high reliability with cheaper equipment when compared with the current scenario. From the resent trends it is given that the IR revenue has obtained a growth of 22,854.67 crores in the financial year of 2018-19. This will be a good sign for growth of chance in utilizing the revenue for research and development of IR in future.

5. Conclusion

This paper provides a glance on the signalling in IR and various standards that are followed for smooth working of it. The recent stats had proved that IR is going to be the most emerging railway network with lots of scope for research and development in the field of signalling and safety. The survey concludes that various standards has been adopted to stabilize the densely populated traffic in an organized manner by efficiently utilizing the available track length. And the way to the future is by using wireless sensor networks (WSN) to achieve reliability, scalability, cost effectiveness and deterministic data transfer. In future potential research can be done in modelling the MAC layer through TSCH and various power sensors can be analyzed. This work is a perfect review and when implemented in sensor networks can be a low cost replacement to the current CBTC implementation which was applied in current Vande Bharath Trains in India. This low cost WSN review enables researchers to find out more low cost power efficient solutions which can save lot of money not only in IR , elsewhere also.

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